



Wind farm design in complex terrain: the FarmOpt methodology

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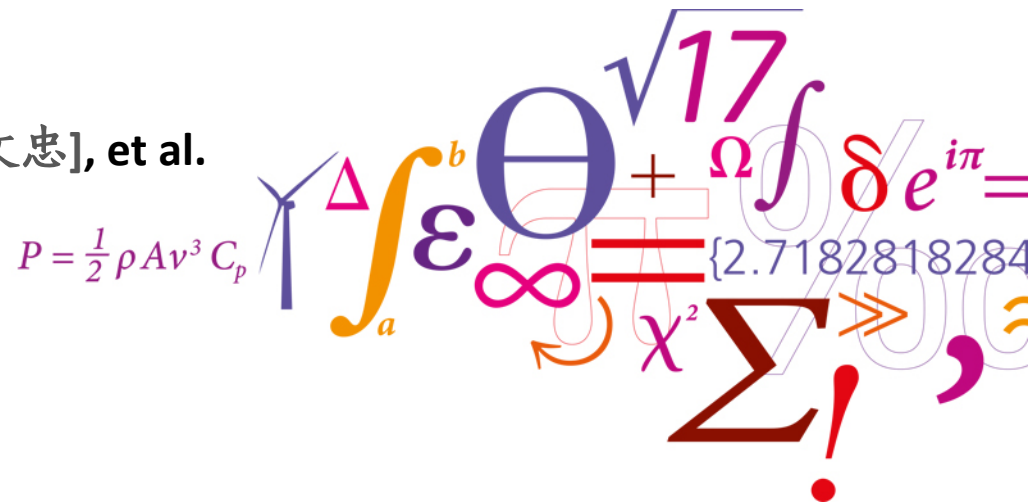
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Wind Farm Design in Complex Terrain: The FarmOpt Methodology

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Outlines

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- 3. Layout Optimization
- 4. Test Case
- 5. Conclusions & Future Developments



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0. DTU Wind Energy (Technical University of Denmark)



DTU Wind Energy is one of the world's largest centres of wind energy research and knowledge, with a staff of more than 250 people working in research, innovation, research-based consulting and education.

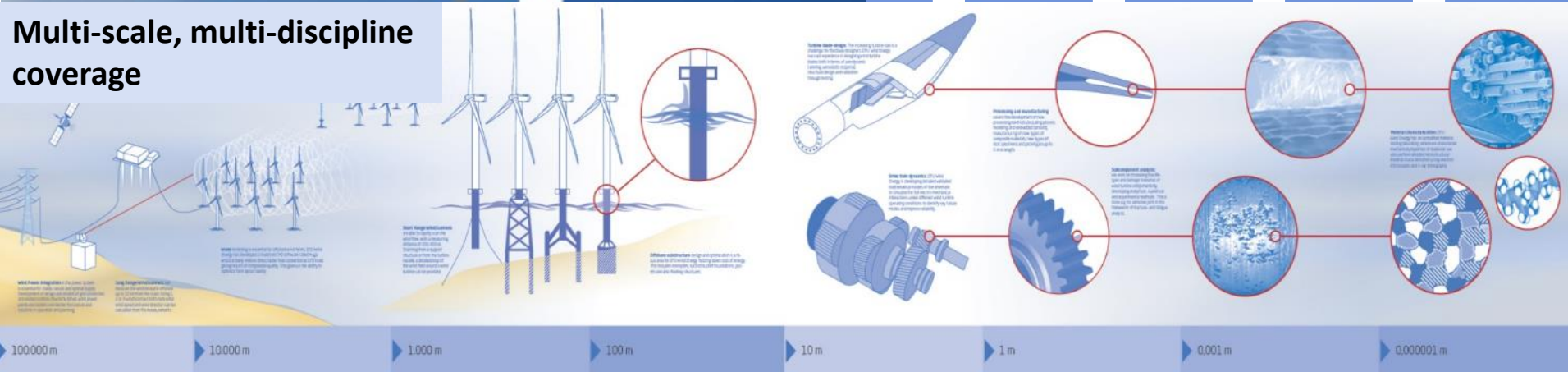
0. DTU Wind Energy (Technical University of Denmark)



DTU Wind Energy



Multi-scale, multi-discipline coverage



Siting and integration

Offshore wind energy

Wind turbine technology

Education and teaching

Research based consultancy and tests

1. Introduction

- ❑ More wind farms in complex terrain (esp. China)
- ❑ Great potential & many challenges
 - Richer wind resources
 - More complex flow, more expensive O&M
- ❑ Wind resource based micro-siting insufficient

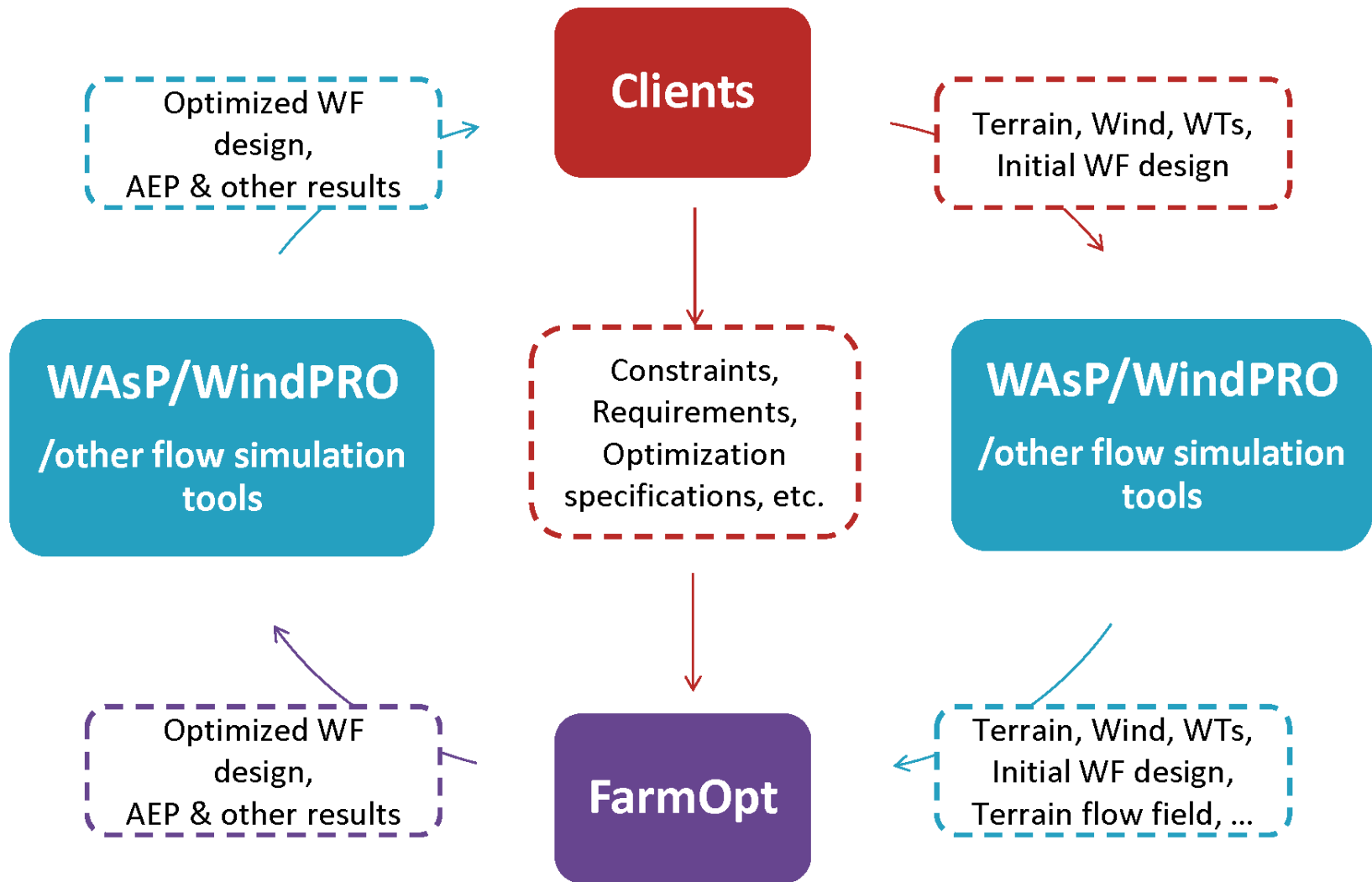


□ The FarmOpt methodology:

- State-of-the-art flow simulation tool (WAsP CFD) +
- Adapted wake model +
- Advanced layout optimization algorithm +
- Realistic constraints or requirements.

□ The FarmOpt tool:

- Standard-alone tool
- Modular design written in Python
- Will be integrated with WindPRO and WAsP.



Flowchart of using FarmOpt

2. Wind Farm Modelling

☐ Wind resource

- Sector-wise Weibull parameters, speed-up factors, turning-angles, mean wind speeds, etc.
- Obtained from standard wind resource assessment tools (WAsP, WindPRO)

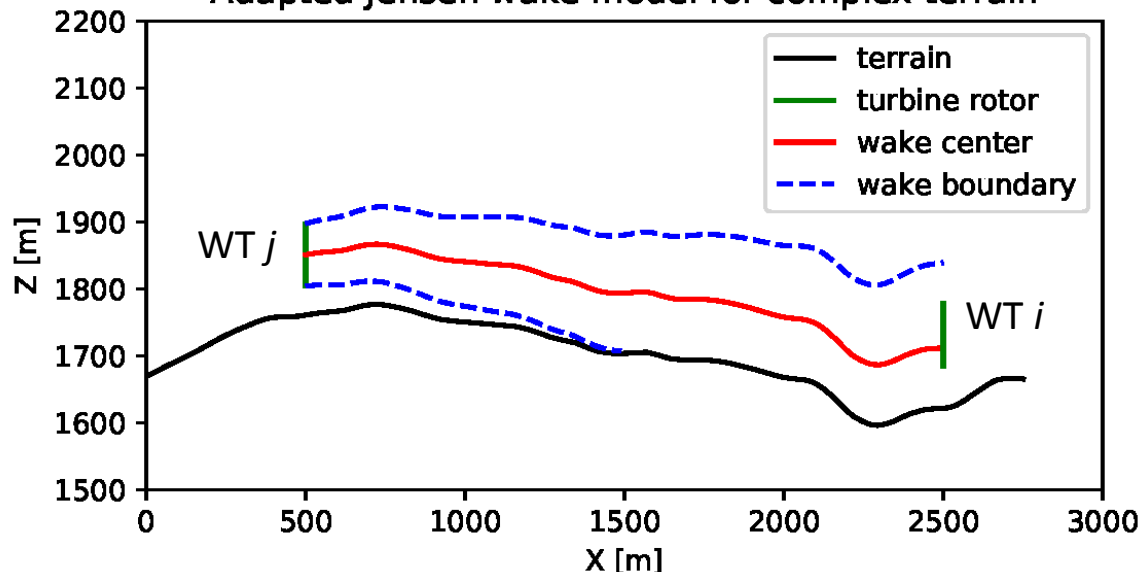
☐ Constraint modelling

- Inclusive boundaries, exclusive zones, ...
- Minimal mean wind speed, TI, ...
- Maximal terrain ruggedness degree, slope, ...
- Minimal distance between any two turbines, ...

□ Wake modelling (adapted Jensen wake model)

- Wake center follows terrain ground along wind direction
- Velocity deficit and wake zone radius develop linearly according to the travelling distance
- Multiple wakes and/or partial wakes merged at rotor satisfying the kinetic energy deficit balance assumption

Adapted Jensen wake model for complex terrain



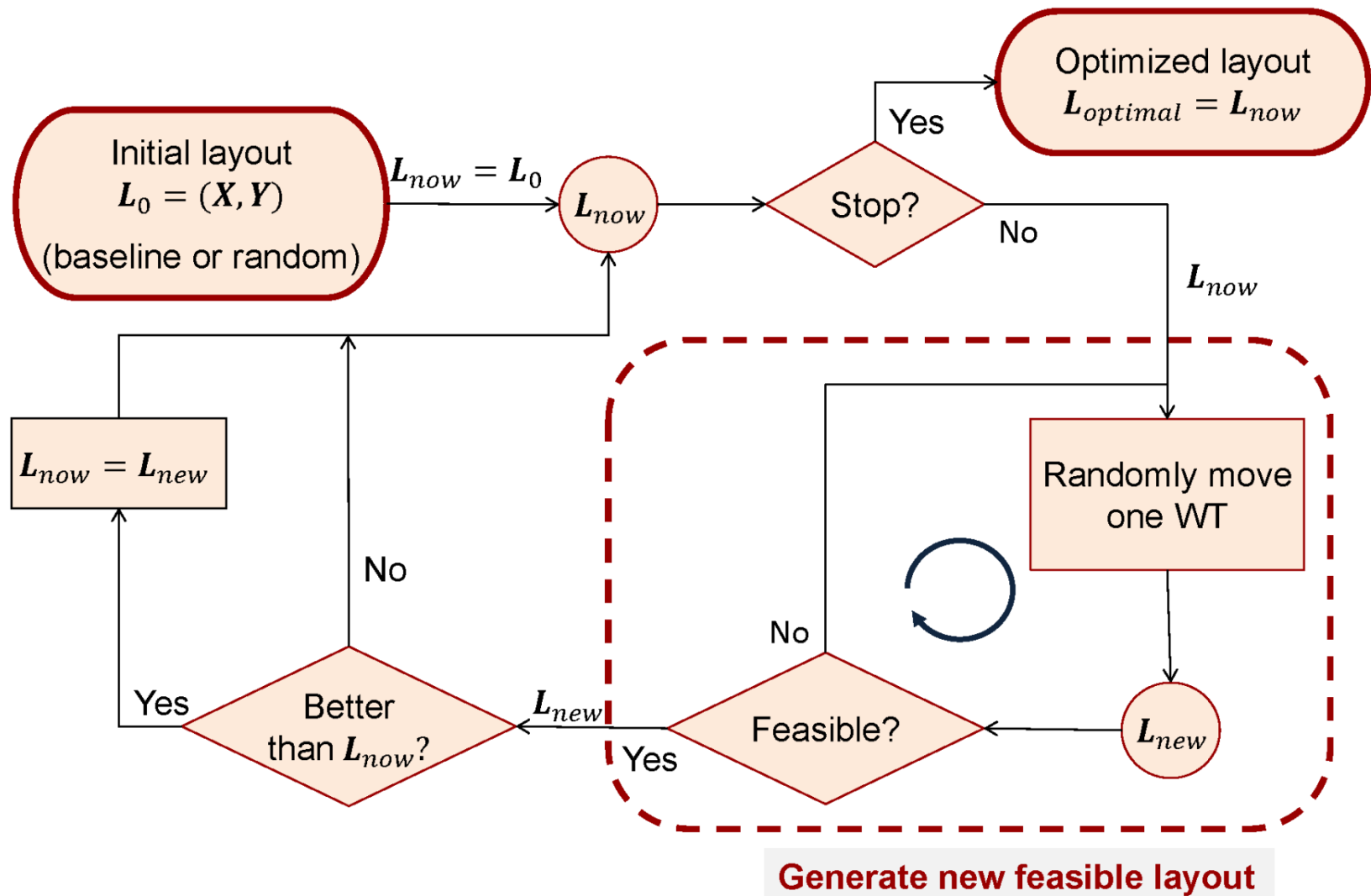
Wake influence wind speed and wake zone radius of WT_j 's wake zone at WT_i 's location:

$$V_{ij} = S(x_j) V_0 \left[1 - \frac{1 - \sqrt{1 - C_T(S(x_j) V_0)}}{(1 + \alpha (s_{ij}/R_r))^2} \right]$$

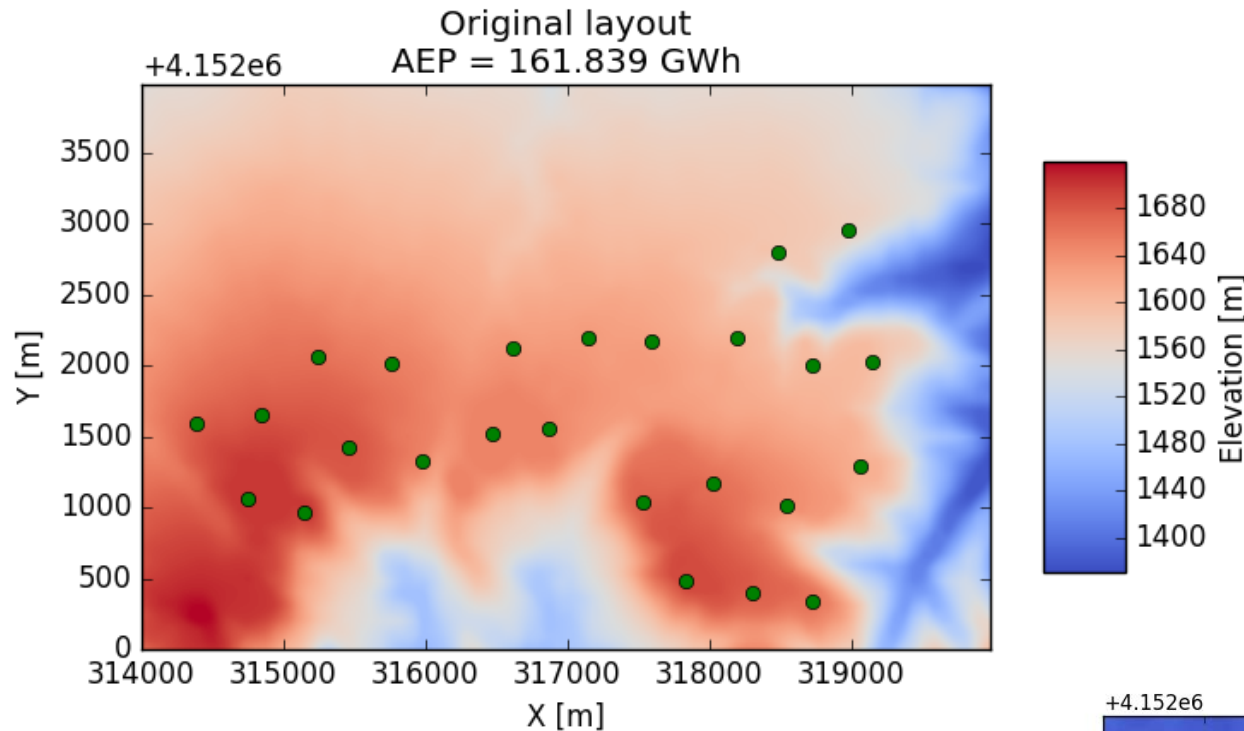
$$R_{ij} = \alpha s_{ij} + R_r$$

[Ref] Feng, J., & Shen, W. Z. (2014). [Wind farm layout optimization in complex terrain: A preliminary study on a Gaussian hill](#). In Journal of Physics: Conference Series (Vol. 524, No. 1, p. 012146).

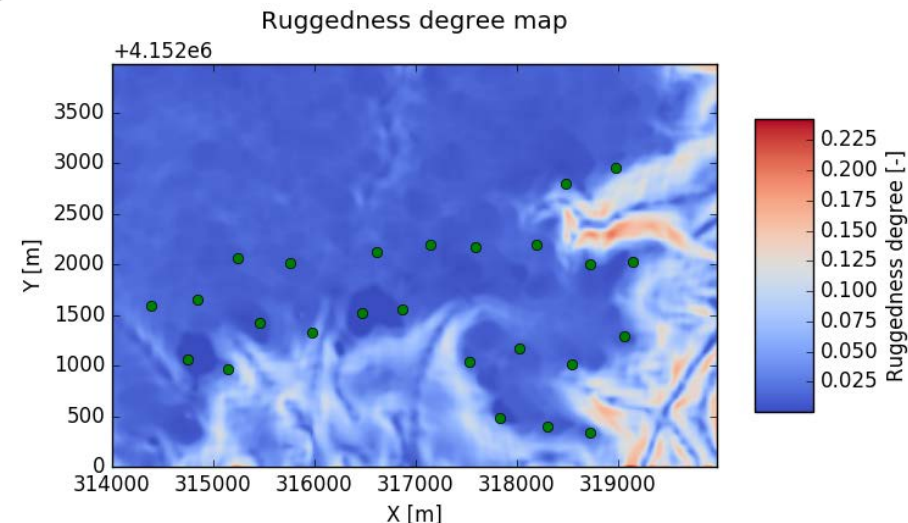
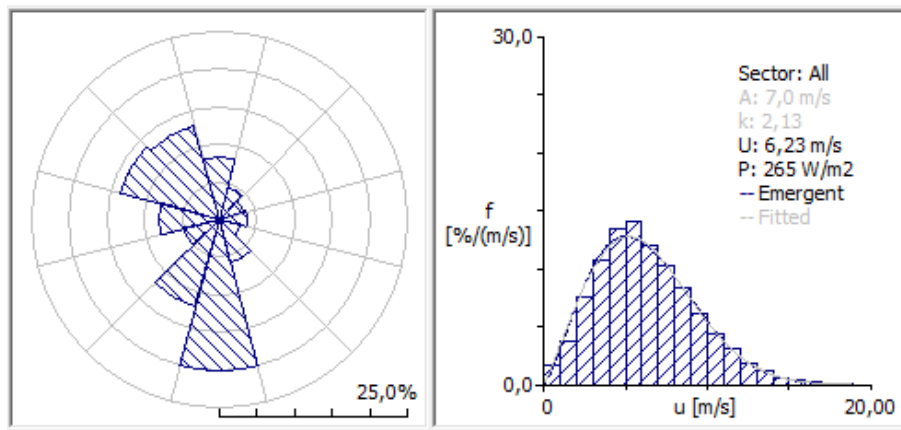
3. Layout Optimization (Random Search)



4. Case study (a 25 turbine wind farm in China)

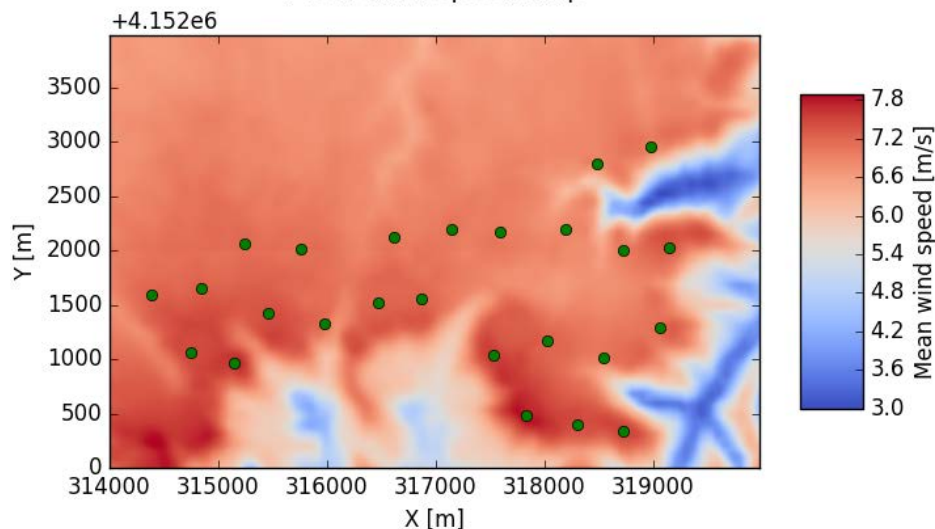


- 2 MW turbine by a Chinese OEM
- D: 93 m, H: 67 m
- Located in Northwest China
- Mean wind speed: 6.23 m/s

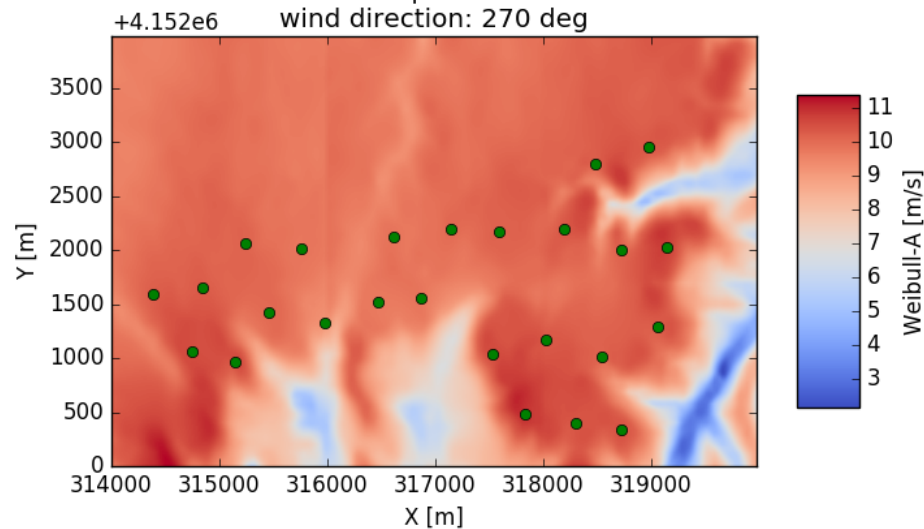


Wind resource and terrain effects from WAsP

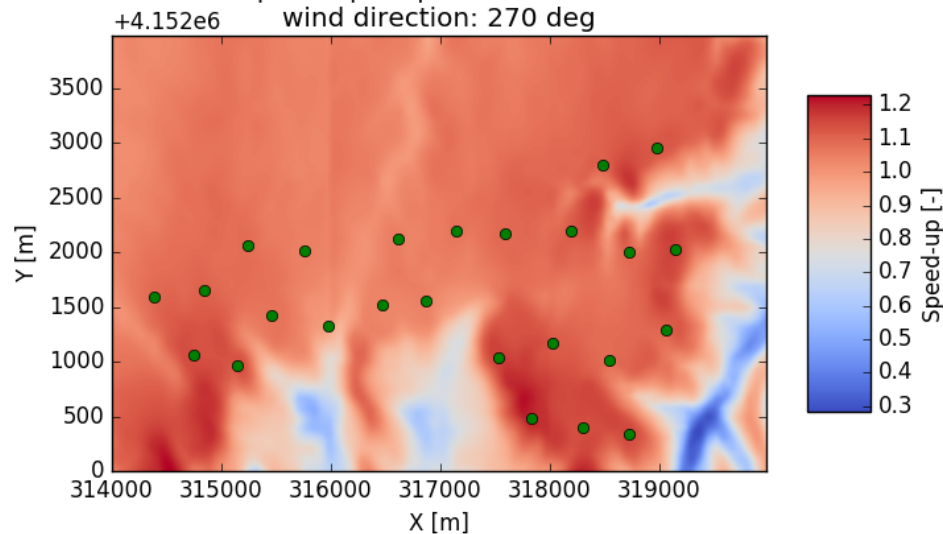
Mean wind speed map



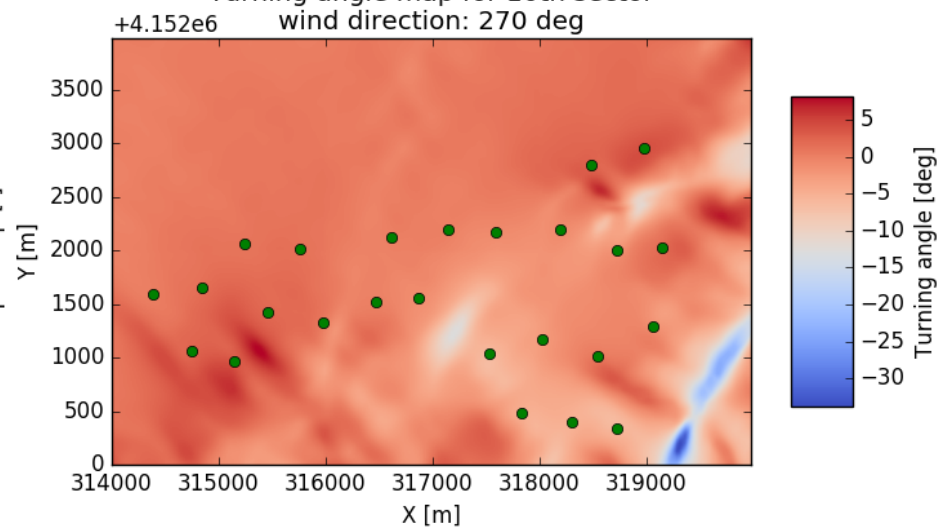
Weibull-A map for 10th sector
wind direction: 270 deg



Speed-up map for 10th sector
wind direction: 270 deg

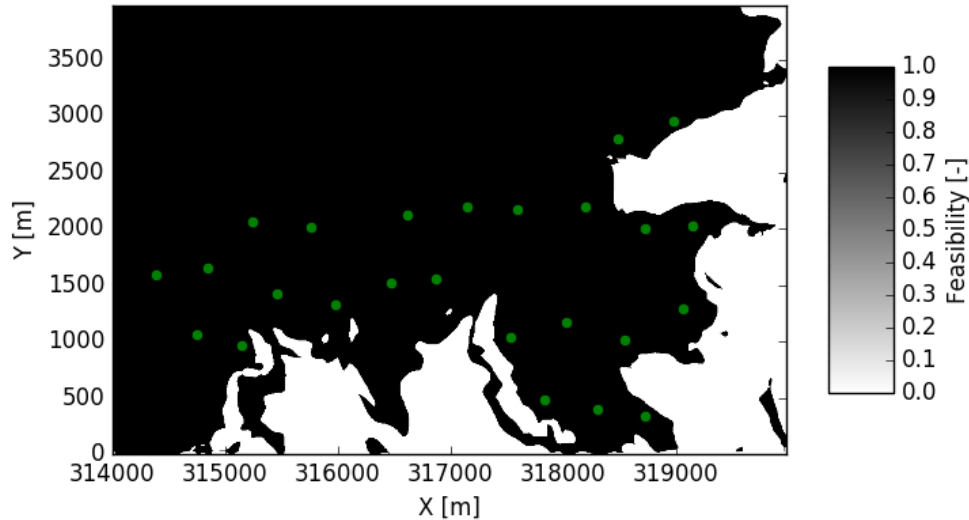


Turning angle map for 10th sector
wind direction: 270 deg



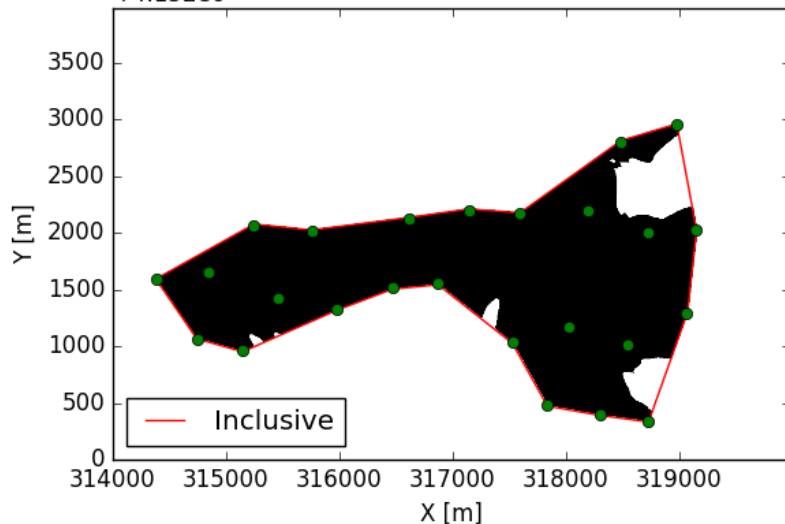
Constraints

Feasibility map ($U_{\text{mean}} \geq 6.0 \text{ m/s}$, $RD \leq 0.08$)
+4.152e6

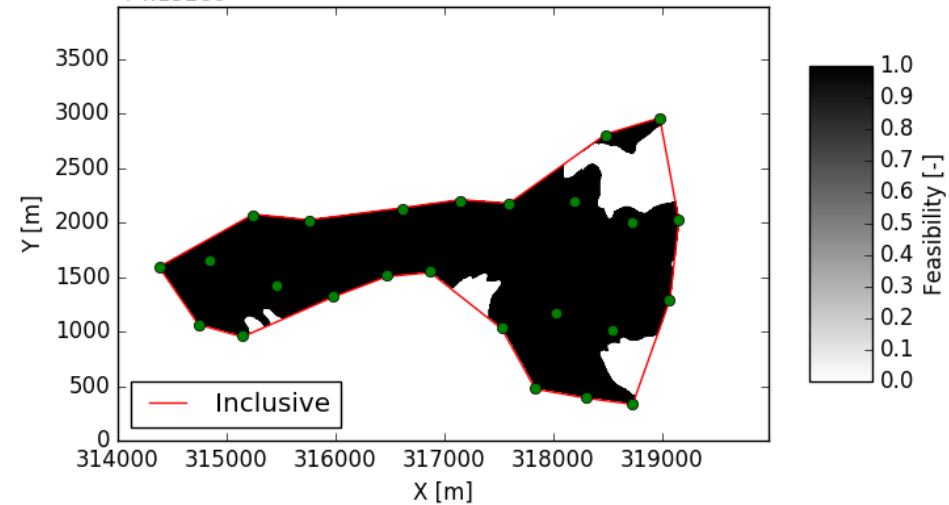


- Minimal U_{mean}
- Maximal ruggedness degree (RD)
- Minimal distance ($D_{\text{min}} = n \cdot D$)
- Inclusive boundary
- Exclusive boundaries
- Others on such as turbulence intensity, total capacity, noise ...

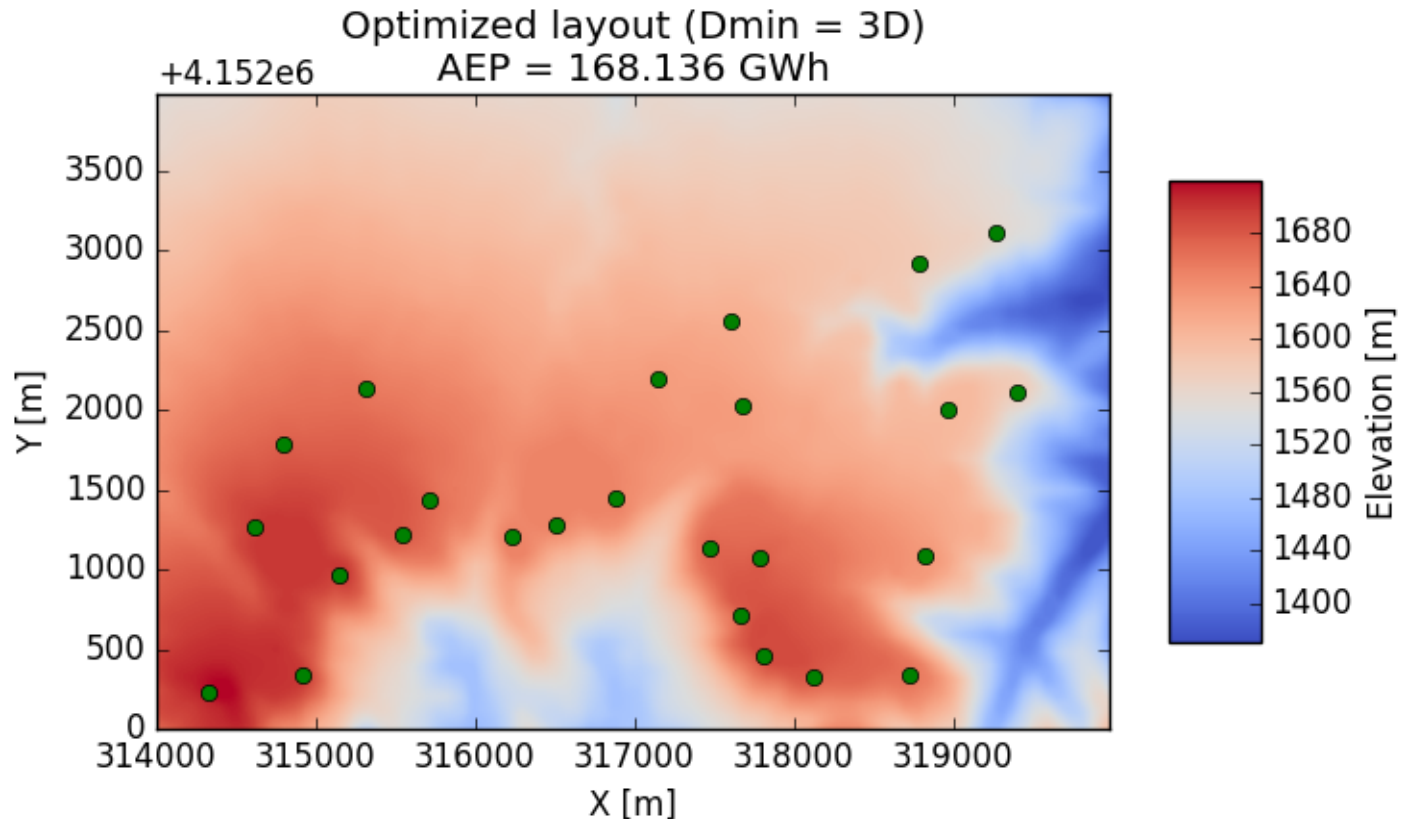
Feasibility map ($U_{\text{mean}} \geq 6 \text{ m/s}$, $RD \leq 0.08$)
+4.152e6



Feasibility map ($U_{\text{mean}} \geq 6.5 \text{ m/s}$, $RD \leq 0.06$)
+4.152e6

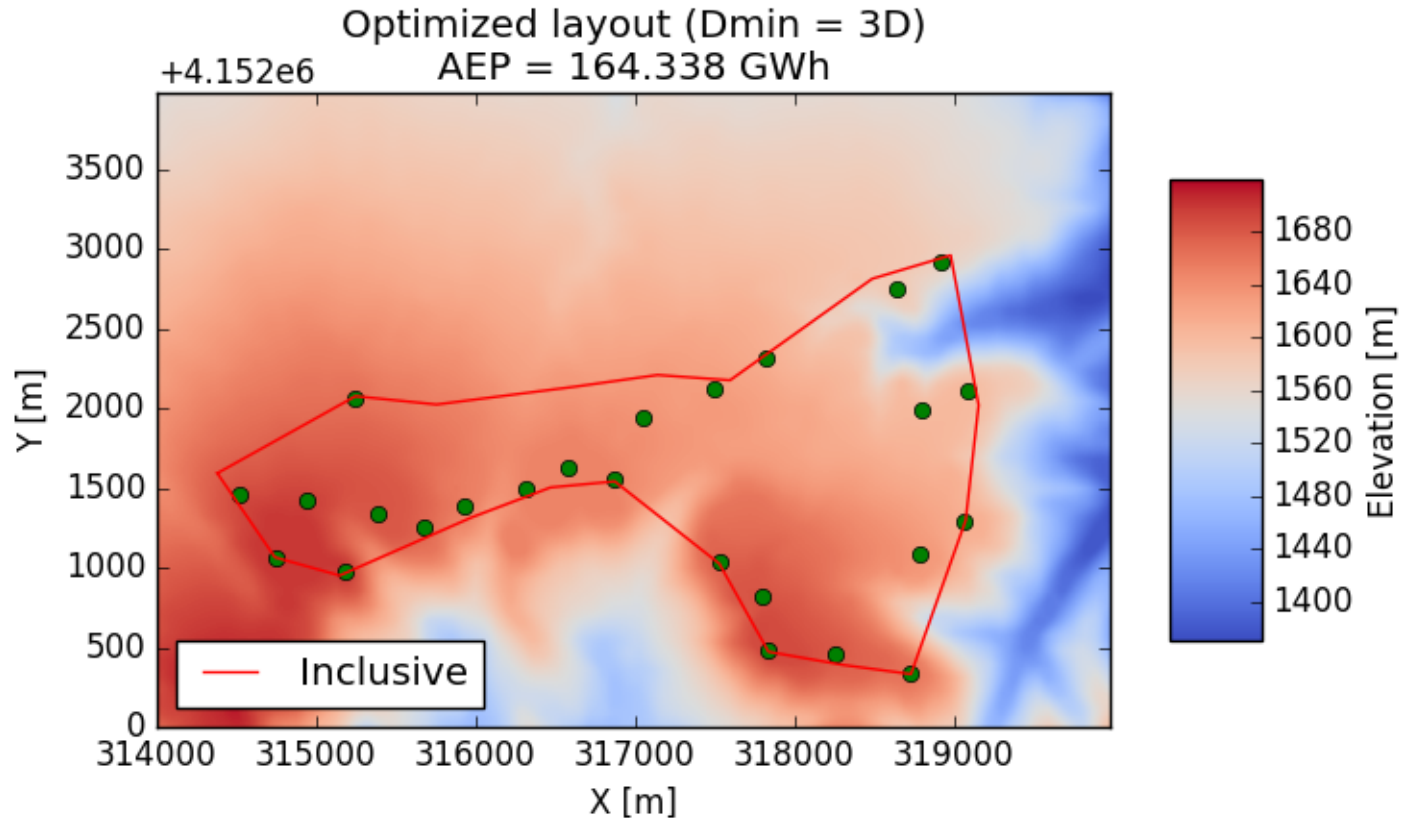


Optimized layout: scenario 1



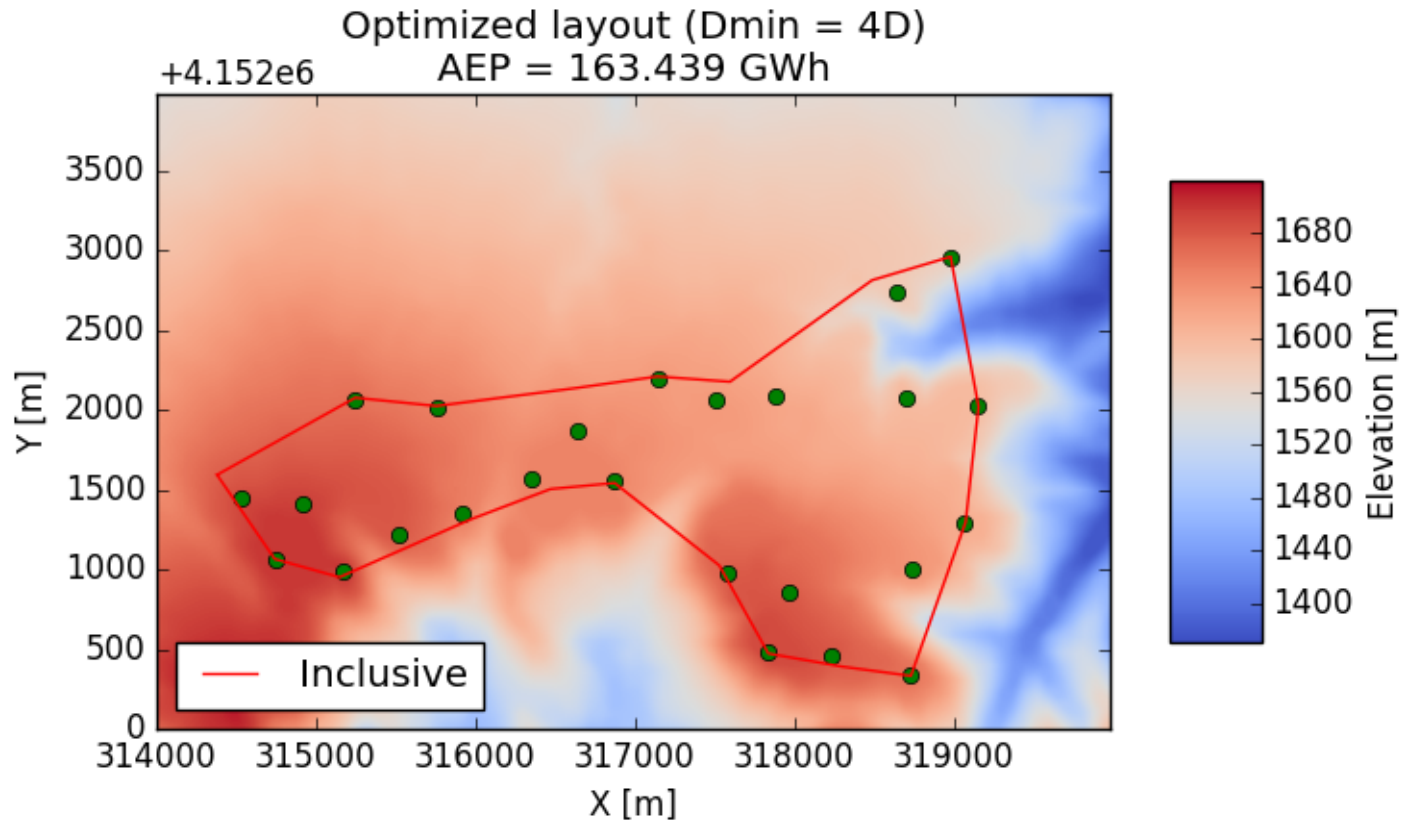
- Constraints: $U_{\text{mean}} \geq 6$ m/s, $RD \leq 0.08$, $D_{\text{min}} = 3D$
- No inclusive boundary
- Net AEP improvement: 161.839 GWh to 168.136 GWh **(+3.89%)**
- Number of evaluations: 1000, cpu time: 12300 s.

Optimized layout: scenario 2



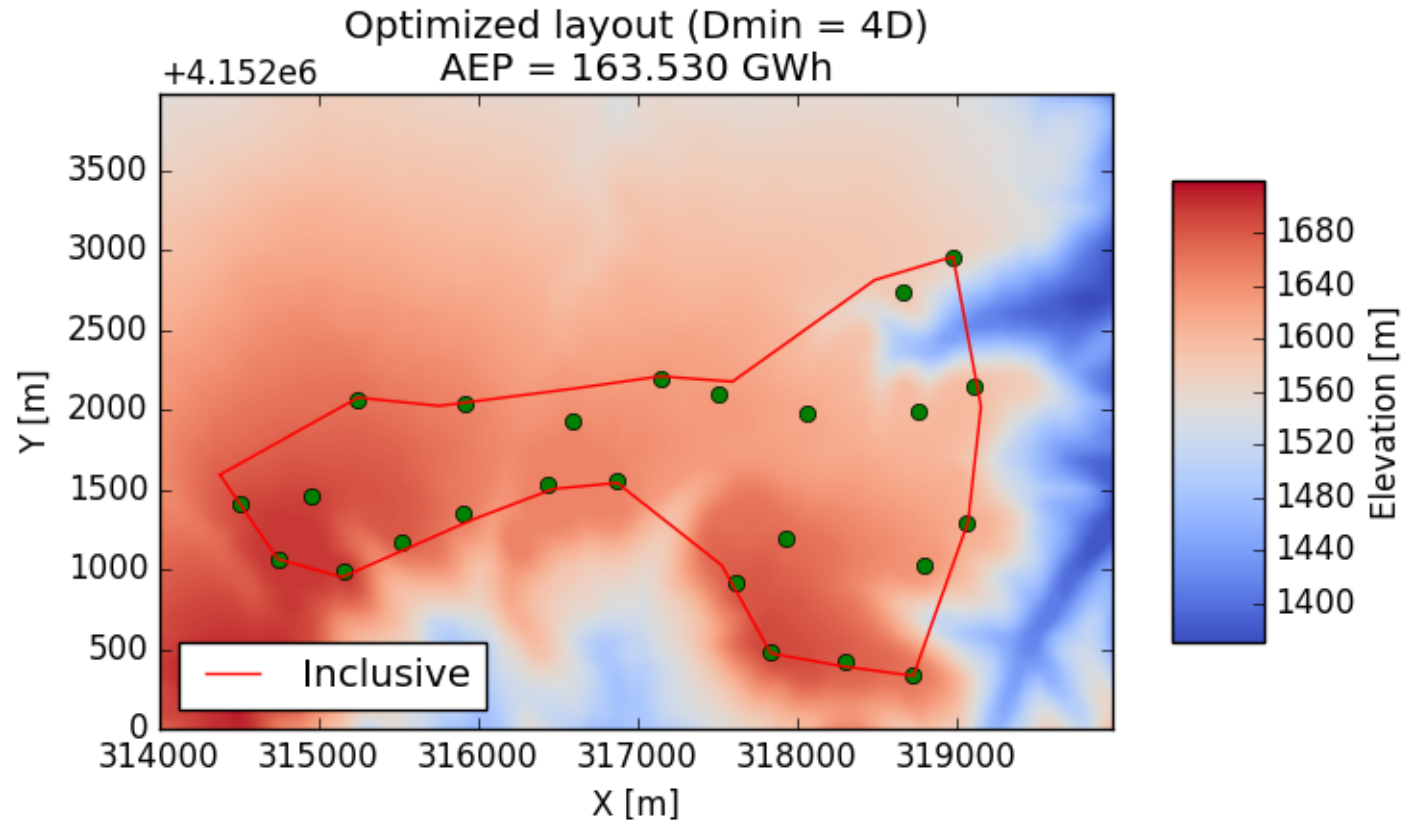
- Constraints: $U_{\text{mean}} \geq 6 \text{ m/s}$, $RD \leq 0.08$, $D_{\text{min}} = 3D$
- With inclusive boundary
- Net AEP improvement: 161.839 GWh to 164.338 GWh **(+1.54%)**
- Number of evaluations: 1000, cpu time: 11257 s.

Optimized layout: scenario 3



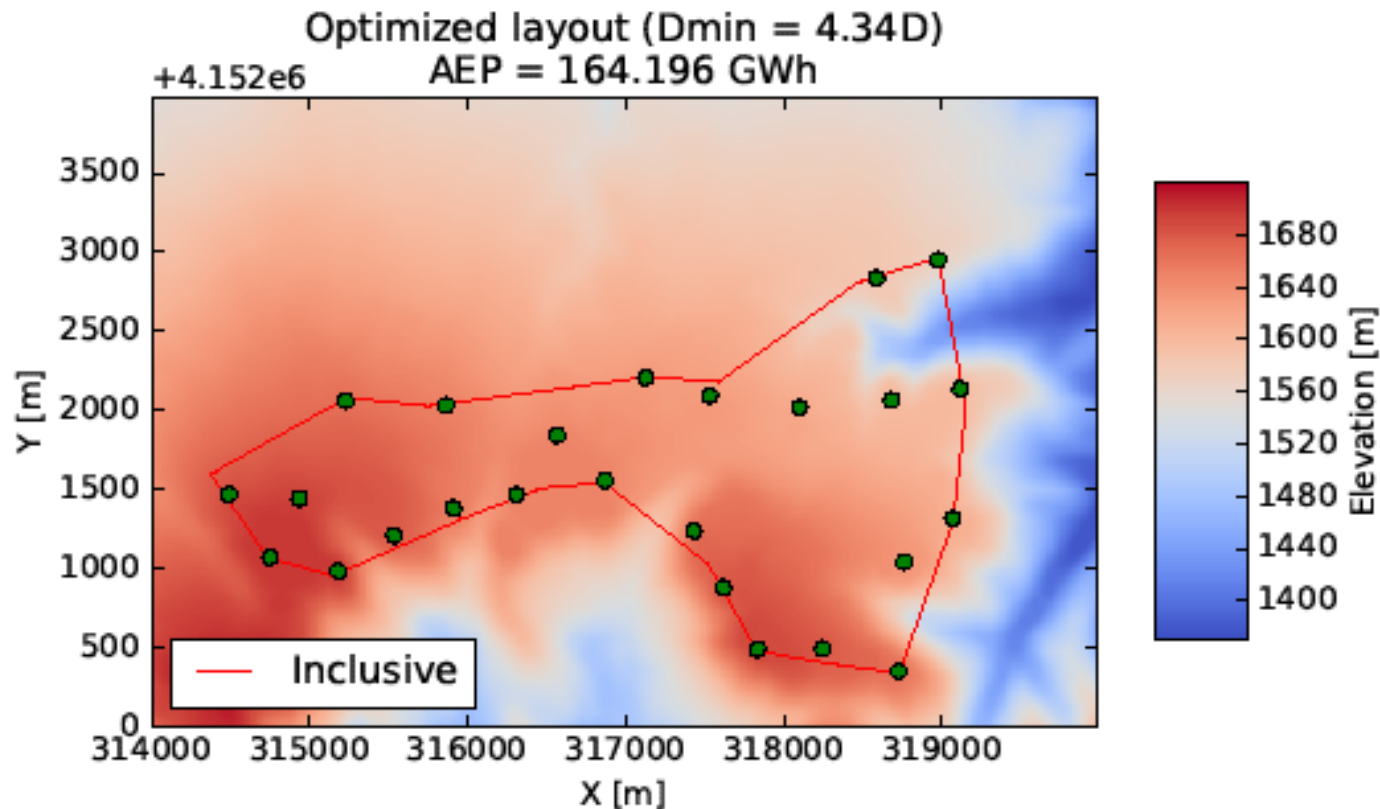
- Constraints: $U_{\text{mean}} \geq 6$ m/s, $RD \leq 0.08$, $D_{\text{min}} = 4D$
- With inclusive boundary
- Net AEP improvement: 161.839 GWh to 163.439 GWh **(+0.99%)**
- Number of evaluations: 1000, cpu time: 11264 s.

Optimized layout: scenario 4



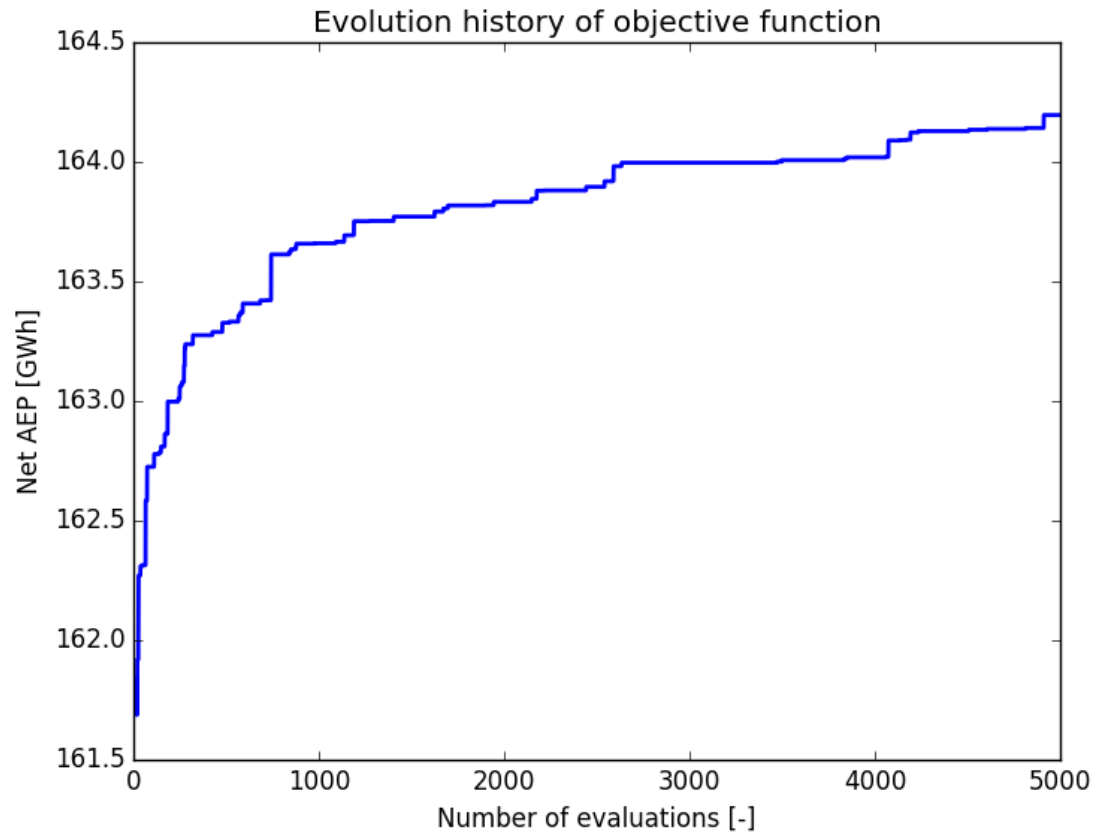
- Constraints: $U_{\text{mean}} \geq 6.5$ m/s, $RD \leq 0.06$, $D_{\text{min}} = 4D$
- With inclusive boundary
- Net AEP improvement: 161.839 GWh to 163.530 GWh **(+1.05%)**
- Number of evaluations: 1000, cpu time: 12099 s.

Optimized layout: scenario 5



- Constraints: $U_{\text{mean}} \geq 6.5 \text{ m/s}$, $RD \leq 0.06$, $D_{\text{min}} = 4.34D$ (current min.)
- With inclusive boundary
- Net AEP improvement: 161.839 GWh to 164.196 GWh **(+1.46 %)**
- Number of evaluations: 5000, cpu time: 63278 s.

Optimized layout: scenario 5



- Constraints: $U_{\text{mean}} \geq 6.5$ m/s, $RD \leq 0.06$, $D_{\text{min}} = 4.34D$ (current min.)
- With inclusive boundary
- Net AEP improvement: 161.839 GWh to 164.196 GWh **(+1.46 %)**
- Number of evaluations: 5000, cpu time: 63278 s.

5. Conclustions & Future Developments

- ❑ FarmOpt: a valuable tool for wind farm design
- ❑ On-going developments
 - More accurate wake model by considering streamlines
 - Parallization and optimization for faster computation
- ❑ Planned developments
 - Overall design optimization
 - Integrated optimization of wind farm design and control
- ❑ A member of the synchronized DTU wind energy toolbox ...



Thanks for your attention!



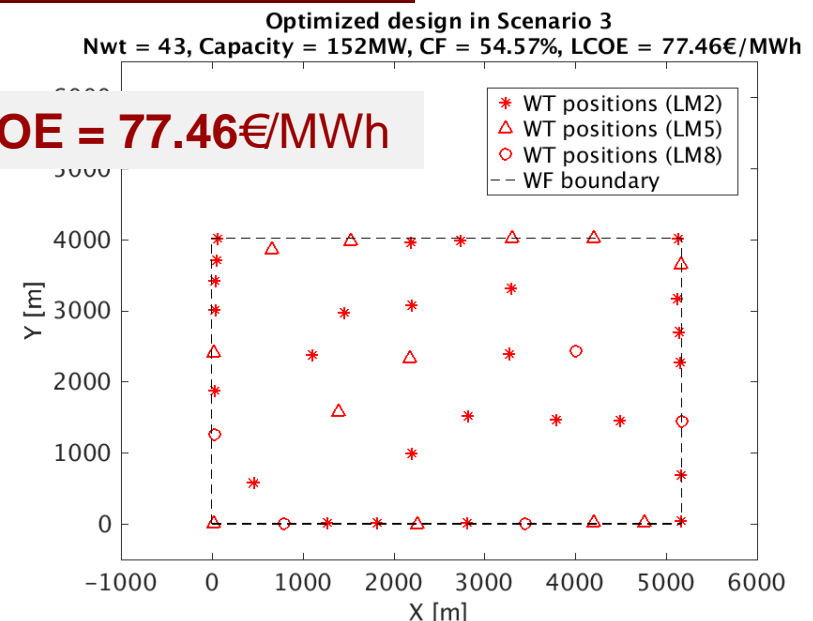
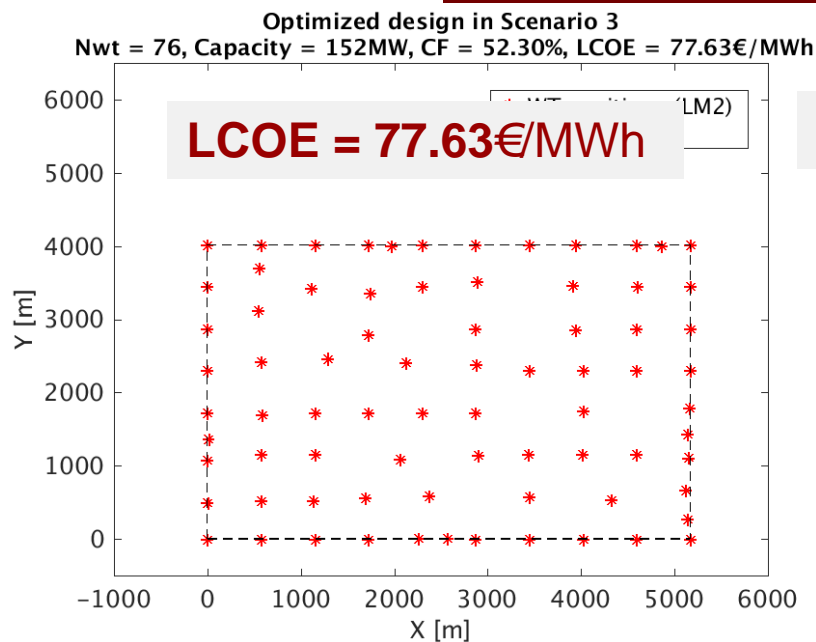
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Appendix

Overall design optimization:

optimizing number, configurations, locations of turbines, electrical cables, access road to min. LCOE or max. IRR with more realistic constraints, such as fatigue/extrem loads, noise, etc.

*Design optimization of non-uniform wind farm
(number, configurations, locations of turbines)*



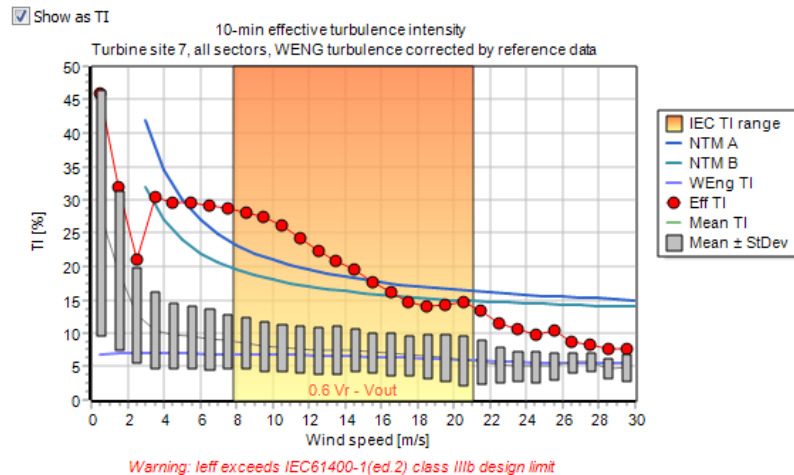
[Ref] Feng, J., & Shen, W. Z. (2017). [Design optimization of offshore wind farms with multiple types of wind turbines](#), Applied Energy 205, 1283–1297.

□ Integrated optimization of wind farm design and control: including wind farm control strategies as optimization variables.

Automatic optimal sector management combined with design optimization

Allowing turbines placed closer to utilize limited high wind sites, and deal with excessive loads for certain wind directions by optimally stopping or derating certain turbines, to comply with IEC requirements on TI. The net AEP could be increased while constraints on loads satisfied.

Effective TI, no management



Effective TI with management

